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ON THE INFLUENCE OF THE MAGNETIC FIELD ON THE CHARACTER OF TURBULENCE IN THE IONOSPHERE

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A great variety of physical conditions is characteristic of the upper atmosphere along the vertical. At the height of 80-100 km. and higher the atmosphere becomes noticeably conductive and various processes there begin to undergo the influence of the Earth magnetic field. In the present paper we shall consider the question of the influence of the magnetic field on the character of turbulent motions in the ionosphere. It seems reasonable for the purpose to use the equations of magnetohydrodynamics of an incompressible viscous fluid:

$$\frac{\partial \vec{v}}{\partial t} + (\vec{v}\nabla)\vec{v} = -\frac{\nabla p}{\rho} + \frac{1}{4\pi\rho}\left[\mathrm{rot}\,\vec{H}\cdot\vec{H}\right] + \nu\Delta\vec{v}; \qquad (1)$$

$$\frac{\partial \vec{H}}{\partial t} = \mathrm{rot}\left[\vec{v}\vec{H}\right] + \nu_m\Delta\vec{H}; \qquad \nu_m = c^2/4\pi\sigma; \qquad (2)$$

$$\mathrm{div}\,\vec{v} = 0; \qquad (3)$$

$$\mathrm{div}\,\vec{H} = 0. \qquad (4)$$

The parameter ν_m is the so-called magnetic viscousity which is inversely proportional to conductivity of the medium σ (in the Gauss system of units the dimension of σ is equal to sec^{-1}). Other notations used are ordinary.

Let us consider some consequences of these equations. Consider the characteristic scale of motion L and the characteristic velocity U. Then the ratio of terms in the right-side of the equation (2) has the order of magnitude

$$\frac{UL}{\nu_m} = R_m \qquad (5)$$

The number R_m is the so-called ~~reffered to as the~~ magnetic Reynolds number. It is usefull to kepp in mind its connection with hydrodynamical Reynolds number:

$$R_m = R\frac{\nu}{\nu_m} . \qquad (5')$$

If for the considered kind of motion R_m is much greater than unity then the term of the equation(2) describing the dissipation of fields can be neglected and the well known theorem about the frozen-in ~~ess~~ ~~of the~~ fields ~~into fluid~~ is valid. According to this theorem the movements of the force lines of the magnetic field are impossible with respect to the medium. In this case the field has the same scale change as the other quantities. The role of the field in the dynamics of the medium can be characterized (See Eq.(1)) with a parameter

$$\eta = H^2/8\pi p . \qquad (6)$$

The influence of the field is not essential if $\eta << 1$.

Let's consider the second extreme case when $R_m \lesssim 1$. In the equation (2) the term describing the dissipation of the field due to finite conductivity surpasses one describing the inductional increase of the field due to the movements in the fluid. In this case the scale change of the field is mainly determined by conductivity of the fluid and it is equal in order of magnitude to $L_1 = \nu_m / U$. Let's estimate the influence of the field here. In the Navier-Stokes equation the term ∇p has the order of magnitude p/L, the term $\frac{1}{4\pi}[\mathrm{rot}\vec{H}\cdot\vec{H}]$ is of the order $H^2/8\pi L_1 = H^2U/8\pi\nu_m$ and its ratio is equal to the number:

$$K = H^2UL/8\pi\nu_m p = \eta R_m. \tag{7}$$

The influence of the magnetic field is negligible if $K \ll 1$.

We shall turn now to consideration of the turbulence in the conductive medium in the presence of the magnetic field. If the influence of the field on the minimum scales of turbulence is not essential, it might be assumed that dissipation of the turbulent energy is the result of the effect of viscousity. The small scale turbulence will then be of the usual character and will be similar to that of the usual atmospheric turbulence. For the inner (minimum) scale of turbulence l_0 in the well-developed turbulent stream the own Reynolds number $u_0 l_0 / \nu$ is eqoal to unity in the order of magnitude. In this case the condition (5) will become

$$\nu/\nu_m >> 1. \tag{8}$$

When here $\eta \ll 1$ the influence of the field can be neglected.

If η is greater than unity or has its order of magnitude it may be expected that the usual representation of the theory of turbulence will loose its validity as the strong magnetic field in this case stabilizes the movements of the greater scales than l_0 .

Let's consider the medium with bad conductivity. The influence of the field on turbulence as obtained from the condition (9) is not essential if

$$\nu\eta/\nu_m \ll 1 . \qquad (9^*)$$

The criteria (8) and (9) have been applied to the real conditions of the upper atmosphere for the purpose of clarifying the question whether the Earth magnetic field influences on the character of turbulence. The results for different heights are tabulated below.

z KM	ν_m cm^2/sec	ν cm^2/sec	η	λ cm	Criterium(8)or(9)
80	7.10^{15}	2.10^3	2.10^{-5}	0.4	$\nu\eta/\nu_m=5.10^{-18} \ll 1$
100	2.10^{15}	10^5	10^{-3}	6	$\nu\eta/\nu_m=5.10^{-14} \ll 1$
150	10^{11}	2.10^7	0.1	5.10^2	$\nu\eta/\nu_m=2.10^{-5} \ll 1$
200	5.10^9	2.10^8	1	10^4	$\nu\eta/\nu_m=0.04 \ll 1$
250	7.10^8	2.10^9	5	10^5	$\nu/\nu_m=3$; $\eta > 1$
300	10^9	8.10^9	20	4.10^5	$\nu/\nu_m=8$; $\eta \gg 1$

The magnetic field was admitted to be 0.5 gauss in these estimations. The rest quantities approximated to the first figure were taken from Mitra's book [1]. The latest data obtained from rocket and sputnik measurements were not used in our estimations as they would not essentially change our results. From the given table it is seen that up to the height of about 200 km. the Earth magnetic field does not effect on the small scale turbulence. At greater heights this effect may exist but the mean free path there is of the order of magnitude of a kilometer. Therefore, the scale of corresponding eddies should be too large to be of interest in the study of scattering of radiowaves.

Thus, we know the order of magnitude of the product $u_0 \ell_0$. It is equal to the kinematic viscousity ν. However, we cannot say anything concrete separately about scales and velocities of the minimum eddies. For this we need to know some other characteristic of turbulence from the experiment. In the scientific literature there are indirect conclusions on the behaviour of the turbulence-power per unit mass ε along the vertical and estimations of its value [2,3]. Knowing ε we can determine the value u_0 and ℓ_0 separately. In accordance with the dimension theory

$$\ell_0 = \left(\nu^3/\varepsilon\right)^{1/4}. \qquad (10)$$

As ε has a very weak power we neglect its dependence upon the height and it increases the value ℓ_0. Indeed, according to [2] the value of ε increases from $5 \cdot 10^{-4}\, w/kg$ in the troposphere up to $10^{3}\, w/kg$ at the height of about 200 km and its ratio in the power 1/4 is equal to 37. Taking into account that $\nu \sim n^{-1}$ where n is the number of molecules in cm^3 and that the mean free path is also $\lambda \sim n^{-1}$ the following ratio may be obtained

$$\frac{l_0}{\lambda} = \frac{l_{0s}}{\lambda_s}\left(\frac{\varepsilon_s}{\varepsilon}\right)^{1/4}\left(\frac{n}{n_s}\right)^{1/4}. \qquad (11)$$

Here, the quantities with the index s are defined at the surface of the Earth. Thus, the ratio l_0/λ decreases with decrease of density as $n^{1/4}$.
The value $n_s = 2{,}7\cdot10^{19}cm^{-3}$; at the height of 100km $n=4.10^{13}$ and $(n_s/n)^{1/4} = 30$; at the height of 250km $n=3.10^9$ and $(n_s/n)^{1/4} = 300$. The additional decrease of the ratio l_0/λ is the result of the growth ε. At the surface of the Earth $\lambda \approx 10^{-5}$cm and $l_0 \approx 0.1$cm, therefore $l_0/\lambda \approx 10^4$. Under these conditions the molecular scale of length may entirely be neglected for the creation of the theory of turbulence. At the ~~heig~~ height of 250 km the value l_0/λ decreases up to 30 or, may be, even to the smaller values due to the growth of ε. Still more distinctly this situation reveals when considering turbulence in the interstar gas [4]. On the other hand, it may be obvious that in order to ensure the mechanism of viscous dissipation l_0 should be much larger than the mean free path as as the gradients of velocities are small and for their equalization a large number of collisions of mo- should exist. This contradiction makes us apply the known results of the theory of turbulence, which are true and valid for the dense troposphere, to the rarefied gases only very carefully. To create the theory of turbulence for the rarefied gases we should, apparently, take also a mean free path

as a scale of length. It may be shown that to assume so is the same as to take into account the compressibility of fluids (the viscosity ν has the order of magnitude of the product of the sound speed and the mean free path).

Finally, the practical conclusion may be as follows: in spite of all reservations the turbulence in the lower ionopphere at the heights of 100-150 km.is apparently similar to the ordinary atmospheric turbulence and the influence of the Earth magnetic field may be taken into account as a small correction. I would like to thank Prof. A.M.Obukhov and Dr. A.S.Monin for helpful discussions.

REFERENCES

1. Mitra S.K., The Upper Atmosphere., Calcutta, 1952.
2. Booker H.G., J.Gepphys.Res., 61, No.4, 673, 1956.
3. Matuura N., Nagata T., Rep.Ionosph.Res., Japan, Xii, No.2, 147, 1958.
4. Kaplan C.A., Astronomical Journal, U.S.SR., XXXII, No.3, 255, 1955.

Гальперин

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SCATTERING OF WAVES AND MICROSTRUCTURE OF TURBULENCE IN THE ATMOSPHERE.

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Summary

The phenomenon of radio wave-scattering on random inhomogeneities (turbulence) attracted the attention of radio-engineers over the recent 10 - 15 years. A systematic study of this phenomenon may give a valuable information about microstructure of turbulence in the different layers of the atmosphere.

There is an analogy in the theoretical treatment of the problem on scattering for the sound waves and radio waves by turbulence. The theory provides a relation between the characteristics of the scattering and the turbulent spectrum in the general case of homogeneous turbulence (the isotropic character is not assumed here). Thus, experimental determination of the turbulent spectrum and verification of the hypothesis about the isotropic character of turbulence on the basis of observations of the wave-scattering (radio or sound) becomes possible.

Some results of experimental investigations of the sound-scattering by turbulence in the surface layer of the atmosphere were published by Kallistratova,1959. This "experiment in nature" showed an applicability of a new method to the study of the turbulent spectrum. For control, independent mea-

surements of turbulent characteristics were made by routine methods.

The differences in physical parameters characterizing the refraction coefficient for radio waves in the troposphere as well as in the ionosphere do not abolish the possibility of utilizing the similar interpretation method. A principle scheme of experiments for obtaining the quantitative characteristics of the spectrum of turbulent fluctuations of the refraction coefficient (electron density) in the ionosphere might be suggested.